Cognitive Flexibility, Constructivism, and Hypertext:

Random Access Instruction for Advanced Knowledge Acquisition in Ill-Structured Domains

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Introduction: The Complex Context of Learning and The Design of Instruction

A central argument of this paper is that there is a common basis for the failure of many instructional systems. The claim is that these deficiencies in the outcomes of learning are strongly influenced by underlying biases and assumptions in the design of instruction which represent the instructional domain and its associated performance demands in an unrealistically simplified and well-structured manner. We offer a constructivist theory of learning and instruction that emphasizes the real world complexity and ill-structuredness of many knowledge domains. Any effective approach to instruction must simultaneously consider several highly intertwined topics, such as:

- the constructive nature of understanding;
- the complex and ill-structured features of many, if not most, knowledge domains;
- patterns of learning failure;
- a theory of learning that addresses known patterns of learning failure.

Based on a consideration of the interrelationships between these topics, we have developed a set of principal recommendations for the development of instructional hypertext systems to promote successful learning of difficult subject matter (see Spiro, Coulson, Feltovich, and Anderson, 1988; Spiro and Jehng 1990). This systematic, theory-based approach avoids the ad hoc character of many recent hypertext-based instructional programs, which have too often been driven by intuition and the power of the technology.

In particular, we argue that various forms of conceptual complexity and case-to-case irregularity in knowledge domains (referred to collectively as ill-structuredness) pose serious problems for traditional theories of learning and instruction:

- Cognitive and instructional neglect of problems related to content complexity and irregularity in patterns of knowledge use leads to learning failures that take common, predictable forms. These forms are characterized by conceptual oversimplifications and the inability to apply knowledge to new cases (failures of transfer).
- The remedy for learning deficiencies related to domain complexity and irregularity requires the inculcation of learning processes that afford greater cognitive flexibility: this includes the ability to represent knowledge from different conceptual and case perspectives and then, when the knowledge must later be used, the ability to construct from those different conceptual and case representations a knowledge ensemble tailored to the needs of the understanding or problem-solving situation-at-hand.
- For learners to develop cognitively flexible processing skills and to acquire contentive knowledge structures which can support flexible cognitive processing, flexible learning environments are required which permit the same items of knowledge to be presented and
learned in a variety of different ways and for a variety of different purposes (commensurate with their complex and irregular nature).

- The computer is ideally suited, by virtue of the flexibility it can provide, for fostering cognitive flexibility. In particular, multidimensional and nonlinear hypertext systems, if appropriately designed to take into account all of the considerations discussed above, have the power to convey ill-structured aspects of knowledge domains and to promote features of cognitive flexibility in ways that traditional er-based drill) could not (although such traditional media can be very successful in other contexts or for other purposes). We refer to the principled use of flexible features inherent in computers to produce nonlinear learning environments as Random Access Instruction (Spiro and Jehng, 1990).

Following our injunction to consider all crucial issues in the learning and instruction environment jointly, we will develop the following compound argument, which integrates the claims presented above:

- Characteristics of ill-structuredness found in considered) lead to serious obstacles to the attainment of advanced learning goals (such as the mastery of conceptual complexity and the ability to independently use instructed knowledge in new situations that differ from the conditions of initial instruction). These obstacles can be overcome by shifting from a constructive orientation that emphasizes the retrieval from memory of intact preexisting knowledge to an alternative constructivist stance which stresses the flexible reassembly of preexisting knowledge to adaptively fit the needs of a new situation. Instruction based on this new constructivist orientation can promote the development of cognitive- flexibility using theory -based hypertext systems that themselves possess characteristics of flexibility that mirror those desired for the learner.

In summary, structured aspects of knowledge pose problems for advanced knowledge acquisition that are remedied by the principles of Cognitive Flexibility Theory. This cognitive theory of learning is systematically applied to an instructional theory, Random Access Instruction which in turn guides the design of nonlinear computer learning environments we refer to as Cognitive Flexibility Hypertexts.

**Selective Focus on Advanced Knowledge Acquisition in Ill-Structured Domains**

The argument developed in this paper is not intended to cover all aspects of constructive mental processing. Similarly, instructional technology is a broad topic that will not be exhaustively addressed in this paper. Rather, we will focus on a set of issues implicated by consideration of some special instructional objectives (Merrill, 1983) and the factors contributing to their attainment. In particular, we will be concerned only with learning objectives important to advanced (post-introductory) knowledge acquisition: to attain an understanding of important elements of conceptual complexity, to be able to use acquired concepts for reasoning and inference, and to be able to flexibly apply conceptual knowledge to novel situations. Furthermore, we will consider only complex and ill-structured domains (to be defined below). This combination of ambitious learning goals and the obliging nature of characteristics associated with certain knowledge domains will be seen to present special problems for learning and instruction that call for special responses at the level of cognitive theory and related instructional interventions.
We will argue that one kind of hypertext approach is particularly appropriate for this constellation of features associated with the instructional context. The omission of other varieties of computer-based instruction from our discussion does not imply any negative evaluation of their merits Indeed, in other instructional contexts the kinds of hypertexts we will discuss would be inappropriate (e.g., computer-based drill would be better suited to the instructional objective of memorizing the multiplication tables (see Jacobson and Spiro 1991b for the presentation of a framework for analyzing instructional contexts to determine the choice of educational technologies).

In what follows, we wish to illustrate how a particular set of factors in the instructional context (including learning goals and the nature of the knowledge domain) and a set of observed learning deficiencies lead jointly to a recommended cognitive and instructional approach.

The Nature of Ill-Structured Knowledge Domains and Patterns of Deficiency in Advanced Knowledge Acquisition

Ill-Structured Knowledge Domains: Conceptual Complexity and Across-Case Irregularity

An ill-structured knowledge domain is one in which the following two properties hold: (1) each case or example of knowledge application typically involves the simultaneous interactive involvement of multiple, wide-application conceptual structures (multiple schemas, perspectives, organizational principles, and so on), each of which is individually complex (i.e., the domain involves concept- and case-complexity); and (2) the pattern of conceptual incidence and interaction varies substantially across cases nominally of the same type (i.e., the domain involves across-case irregularity). For example, understanding a clinical case of cardiovascular pathology will require appreciating a complex interaction among several central concepts of basic biomedical science, and that case is likely to involve differences in clinical features and conceptual involvements from other cases assigned the same name (e.g., other cases of "congestive heart failure"). Examples of ill-structured domains include medicine, history, and literary interpretation. However, it could be argued that even those knowledge domains that are, in the main, more well-structured, have aspects of ill-structuredness as well, especially at more advanced levels of study (e.g., mathematics). Furthermore, we would argue that ill domains which involve the application of knowledge to unconstrained, naturally occurring situations (cases) are substantially ill-structured. For example, engineering employs basic physical science principles that are orderly and regular in the abstract and for textbook applications (Chi, Feltovich, and Glaser, 1981). However, the application of these more well-structured concepts from physics to "messy real-world" cases is another matter. The nature of each engineering case (e.g., features of terrain, climate available materials, cost, etc.) is so complex and differs so much from other cases that it is difficult to categorize it under any single principle, and any kind of case (e.g., building a bridge) is likely to involve different patterns of principles from instance to instance. Similarly, basic arithmetic is well-structured, while the process of applying arithmetic in solving "word problems" drawn from real situations is more ill-structured. For example, consider the myriad ways that arithmetic principles may be signaled for access by different problem situations and problem wordings.

Advanced Knowledge Acquisition Mastery of Complexity and Preparation for Transfer
The objectives of learning tend to differ for introductory and more advanced learning. When first introducing a subject, teachers are often satisfied if students can demonstrate a superficial awareness of key concepts and facts, as indicated by memory tests that require the student only to reproduce what was taught in roughly the way that it was taught. Thus, in introductory learning, ill-structuredness is not a serious problem. Learners are not expected to master complexity or independently transfer their acquired knowledge to new situations. These latter two goals (mastery of complexity and transfer) become prominent only later, when students reach increasingly more advanced treatments of the same subject matter. It is then, when conceptual mastery and flexible knowledge application become paramount goals, that the complexity and across-case diversity characteristic of ill-structured domains become a serious problem for learning and instruction.

Patterns of Advanced Learning Deficiency in Ill-Structured Domains and Remedies in “Cognitive Flexibility Theory”

In this section we briefly review two related bodies of research: the nature of learning failures in advanced knowledge acquisition, and new theoretical approaches to more successful advanced learning and instruction.

Forms of a "reductive bias" in deficient advanced knowledge acquisition. Advanced knowledge acquisition, that very lengthy stage between introductory treatments of subject matter and the attainment of expertise for the subject, has been very little studied (certainly in comparison to the large number of studies of novices and experts e.g., Chase and Simon, 1973, Chi et al., 1981, Feltovich, Johnson, Moller, and Swanson, 1984). However, in our own recent investigations of advanced learning in ill-structured domains, we have found a number of notable results, some of which were somewhat surprising (Coulson, Feltovich and Spiro, 1989; Feltovich, Spiro, and Coulson, 1989; Myers, Feltovich, Coulson, Adami, and Spiro, 1990; Spiro, Feltovich, Coulson, and Anderson, 1989). These results may be summarized as follows:

- Failure to attain the goals of advanced knowledge acquisition is common. For example, when students are tested on concepts that are consensually judged by teachers to be of central importance and that have been taught, conceptual misunderstanding is prevalent.
- A common thread running through the deficiencies in learning is oversimplification. We call this tendency the reductive bias and we have observed its occurrence in many forms. Examples include the additivity bias, in which parts of complex entities that have been studied in isolation are assumed to retain their characteristics when the parts are reintegrated into the whole from which they were drawn; the diiscreteness bias, in which continuously dimensioned attributes (like length) are bifurcated to their poles and continuous processes are instead segmented into discrete steps; and the compartmentalization bias, in which conceptual elements that are in reality highly interdependent are instead treated in isolation, missing important aspects of their interaction (see Coulson et al., 1980; Feltovich et al., 1980; Myers et al., 1990; Spiro et al., 1989; see Coulson et al., 1980; Feltovich et al., 1980; Myers et al., 1990; Spiro et al., 1989, for presentations and discussion of the many reductive biases that have been identified). Of course, the employment of strategies of this kind is not a problem if the material is simple in ways consistent with the reductive bias. However, if real
complexities exist and their mastery is important, such reduction is an inappropriate oversimplification.

- Errors of oversimplification can compound each other, building larger scale networks of durable and consequential misconception.
- The tendency towards oversimplification applies to all elements of the learning process, including cognitive strategies of learning and mental representation, and instructional approaches (from textbooks to teaching styles to testing). These Various sources of simplification bias reinforce each other (e.g., one is more likely to oversimplify if an inappropriately easier learning strategy is also employed in textbooks or teaching because it is simple).

As we will see in the next section, more appropriate strategies for advanced learning and instruction in ill-structured domains are in many ways the opposite of what works best for introductory learning and in more well-structured domains. For example, compartmentalization of knowledge components works as an effective strategy in well-structured domains, but blocks effective learning in more intertwined, ill-structured domains which require high degrees of knowledge interconnectedness. Instructional focus on general principles with wide scope of application across cases or examples works well in well-structured domains (this is one thing that makes these domains well-structured), but leads to seductive misunderstandings in ill-structured domains, where across-case variability and case-sensitive interaction of principles vitiates their force. Well-structured domains can be integrated within a single unifying representational basis, but ill-structured domains require multiple representations for full coverage. For example consider one kind of single unifying representation; an analogy to a familiar concept or experience. We have found that a single analogy may help at early stages of learning, but actually interferes with more advanced treatments of the same concept later on (Spiro et al., 1989; see also Burstein and Adelson, 1990). Any single analogy for a complex concept will always be limited in its aptness, and misconceptions that will develop when the concept is treated more fully can be predicted by knowing the ways in which the introductory analogy is misleading about or under-represents the material to be learned. To summarize, we have found that the very things that produce initial success for the more modest goals of introductory learning may later impede the attainment of more ambitious learning objectives.

There is much that appears to be going wrong in advanced learning and instruction (see also GPEP, 1984; Perkins and Simmons, 1989). The cognitive theories and instructional practices that work well for introductory learning and in well-structured domains not only prove inadequate for later, more advanced treatments of the same topics, but adherence to those theories and practices may produce impediments to further progress. Our conclusion is that a reconceptualization: of learning and instruction is required for advanced knowledge acquisition in ill-structured domains (see also Spiro et al. 1987, 1988, 1989; Spiro and Jehng, 1990; Feltovich Spiro and Coulson, in press). Such a reconceptualization, taking into account the problems posed by domain ill-structuredness and the patterns of advanced learning deficiency observed in our studies is presented next in our discussion of constructivism and a new constructive orientation. Cognitive Flexibility Theory. After a brief survey of the tenets of that theory, we show its implications for the design of computer hypertext; learning environments that are targeted to the features of difficulty faced by advanced learners in ill-structured domains.
Constructivism, Old and New: Cognitive Flexibility Theory and the Promotion of Advanced Knowledge Acquisition

The topic of this special issue of Educational Technology is constructivism. Our interpretation of this term, as it is applied to learning and instruction, is complex. We argue that there are different points in cognitive acts where constructive mental processes occur. First, we take it as an accepted cognitive principle that understanding involves going beyond the presented information. For example, what is needed to comprehend a text is not solely contained in the linguistic and logical information coded in that text. Rather, comprehension involves the construction of meaning: the text is a preliminary blueprint for constructing an understanding. The information contained in the text must be combined with information outside of the text, including most prominently the prior knowledge of the learner, to form a complete and adequate representation of the text's meaning (see Spiro, 1980, for a review; also see Ausubel, 1968; Bartlett, 1932; Bransford and Johnson, 1972; and Bruner, 1963).

However, our approach to constructivist cognition goes beyond many of the key features of this generally accepted view (see Spiro et al., 1987). The interpretation of constructivism that has dominated much of cognitive and educational psychology for the last 20 years or so has frequently stressed the retrieval of organized packets of knowledge, or schemas, from memory to augment any presented information that is to be understood or any statement of a problem that is to be solved. We argue that conceptual complexities and across-case inconsistencies in ill-structured knowledge domains often render the employment of prepackaged (“precompiled”) schemas inadequate and inappropriate. Rather, because knowledge will have to be used in too many different ways for them all to be anticipated in advance, emphasis must be shifted from the retrieval of intact knowledge structures to support the construction of new understandings, to the novel and situation-specific assembly of prior knowledge drawn from diverse organizational loci in preexisting mental representations. That is, instead of retrieving from memory a previously packaged "prescription" for how to think and act, one must bring together, from various knowledge sources, an appropriate ensemble of information suited to the particular understanding or problem-solving needs of the situation at hand. Again, this is because many areas of knowledge have too diverse a pattern of use for single prescriptions, stored in advance, to cover enough of the cases that will need to be addressed (For other discussions of issues related to cognitive flexibility and " inert knowledge", see Bereiter and Scardamalla 1985; Bransford, Franks, Vye, and Sherwood, 1989. Brown, 1989; Brown and Campione, 1981; and Whitehead, 1929.)

Thus, in Cognitive Flexibility Theory, a new element of (necessarily) constructive processing is added to those already in general acceptance, an element concerned primarily with the flexible use of preexisting knowledge (and, obviously, with the acquisition and representation of knowledge in a form amenable to flexible use). (However, also see Bartlett's, 1932, notion of "turning round upon one's schema.") This "new constructivism" is doubly constructive(1)understandings are constructed by using prior knowledge to go beyond the information given; and (2) the prior knowledge that is brought to bear is itself constructed, rather than retrieved intact from memory, on a case-by-case basis (as required by the across-case variability of ill-structured domains). (Also see Bereiter, 1985.) Cognitive Flexibility Theory is a "new constructivist" response to the difficulties of advanced knowledge acquisition in ill-structured domains. It is an integrated theory of learning, mental representation, and instruction.
We now turn our attention to that theory. (Having discussed the relationship of Cognitive Flexibility Theory to constructivism, the latter term will not be used explicitly very often in the remainder of the paper--but it should be understood that when we talk about Cognitive Flexibility Theory, we are referring to a particular constructivist theory.)

**Cognitive Flexibility Theory: A Constructivist Approach to Promoting Complex Conceptual Understanding and Adaptive Knowledge Use for Transfer**

Limitations of space will not permit a detailed treatment of the key features of Cognitive Flexibility Theory in this section. Let it suffice to say that the tenets of the theory are direct responses to the special requirements for attaining advanced learning goals, given the impediments associated with ill-structured features of knowledge domains and our findings regarding specific deficiencies in advanced learning--knowing what is going wrong provides a strong clue for how to fix it. In lieu of any comprehensive treatment, we will discuss here one central aspect of the theory. Then, we will show how that aspect creates implications for the design and use of hypertext learning environments (For more detailed treatments of Cognitive Flexibility Theory, see Spiro et al. 1987,1988, Spiro and Jehng 1990, and Feltovich et al in press).

The aspect of Cognitive Flexibility Theory that we will briefly discuss here and use for illustrative purposes involves the importance of multiple positions of Instructional content. Some other aspects of the theory will be referred to in passing in the context of that discussion (Many of the tenets of Cognitive Flexibility Theory will not be mentioned at all; e.g., the vital importance of students' active participation in learning). A central claim of Cognitive Flexibility Theory is that revisiting the some material, at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives is essential for attaining the goals of advanced knowledge acquisition (mastery of complexity in understanding and preparation for transfer). Content must be covered more than once for full understanding because of psychological demands resulting from the complexity of case and concept entities in ill-structured domains, combined with the importance of contextually induced variability and the need for multiple knowledge representations and multiple interconnectedness of knowledge components (see Spiro et al., 1988, for justifications of all these requirements). Any single explanation of a complex concept or case will miss important facets that would be more salient in a different context or from a different intentional point of view. Some of the representational perspectives necessary for understanding will be grasped on a first or second exploration, while others will be missed until further explorations are undertaken Some useful connections to other instructed material will be noticed and others missed on a single pass (with connections to nonadjacently presented information particularly likely to be missed). And so on. Revisiting material in an ill-structured domain is not a simple repetitive process useful only for forming more durable memories for what one already knows. For example, re-examining a case in the context of comparison with a case different from the comparison context (i.e., the first time the case was investigated ) will lead to new insights (especially if the new "reading" is appropriately guided), this is because partially nonoverlapping aspects of the case are highlighted in the two different contexts. The more complex and ill-structured the domain, the more there is to be understood for any instructional topic, and, therefore, the more that is unfortunately hidden in any single pass, in any single context, for any restricted set of purposes, or from the perspective of any single conceptual model. For example, just consider the importance of multiple knowledge
representations, one thing made possible by multiple passes through the same material. A key feature of ill-structured domains is that they embody knowledge that will have to be used in many different ways, ways that can not all be anticipated in advance. Knowledge that is complex and ill-structured has many aspects that must be mastered and many varieties of uses that it must be put to. The common denominator in the majority of advanced learning failures that we have observed is oversimplification, and one serious kind of oversimplification is looking at a concept or phenomenon or case from just one perspective. In an ill-structured domain, that single perspective will miss important aspects of conceptual understanding, may actually mislead with regard to some of the fuller aspects of understanding, and will account for too little of the variability in the way knowledge must be applied to new cases (Spiro et al., 1989). Instead, one must approach all elements of advanced learning and instruction with the tenet of multiple representations at the center of consideration.

Cognitive Flexibility Theory makes specific recommendations about multiple approaches that range from multiple organizational schemas for presenting subject matter in instruction to multiple representations of knowledge (e.g., multiple classification schemes for knowledge representation). Knowledge that will have to be used in a large number of ways has to be organized, taught, and mentally represented in many different ways. The alternative is knowledge that is usable only for situations like those of initial learning; and in an ill-structured domain that will constitute just a small portion of the situations to which the knowledge may have to be applied.

Given all of this, it should not be surprising that the main metaphor we employ in the instructional model derived from Cognitive Flexibility Theory and in our related hypertext instructional systems) is that of the criss-cross landscape (Spiro et al., 1987; Wittgenstein, 1953), with its suggestion of a nonlinear and multidimensional traversal of complex subject matter, returning to the same place in the conceptual landscape on different occasions coming from different directions. Instruction prepares students for the diversity of uses of ill-structured knowledge, while also demonstrating patterns of multiple interconnectedness and context dependence of knowledge, by crisscrossing the knowledge domain in many ways (thereby also teaching students the importance of considering complex knowledge from many different intellectual perspectives, tailored to the context of its occurrence. This should install an epistemological belief structure appropriate for structured domains and provide a repertoire of flexible knowledge representations that can be used in constructing assemblages of knowledge, taken from here and from there, to fit the diverse future cases of knowledge application in that domain.

**Constraints on the Design of Hypertext Learning Environments Drawn from Implications of Cognitive Flexibility Theory**

Thus far, we have discussed the relationships between the nature of ill-structured knowledge domains and difficulties in the attainment of advanced learning goals (mastery of complexity and transfer to new situations). A principle of Cognitive Flexibility Theory was then introduced as one antidote to the problems of advanced knowledge acquisition in ill-structured domains. Now, we will briefly point to some of the ways that these cumulative considerations impinge on the design and use of hypertext learning environments.
First, the preceding discussion should make it reasonably clear that hypertext environments are good candidates for promoting cognitive flexibility in ill-structured domains. We have referred to the need for rearranged instructional sequences, for multiple dimensions of knowledge representation, for multiple interconnections across knowledge components, and so on. Features like these correspond nicely to well known properties of hypertext systems, which facilitate flexible restructuring of instructional presentation sequences, multiple data codings, and multiple linkages among content elements. It appears straightforward that a nonlinear medium like hypertext would be very well suited for the kinds of "landscape criss-crossing" recommended by Cognitive Flexibility Theory and needed in ill-structured knowledge domains (see also Bednar, Cunningham, Duffy, and Perry, 1991).

However, it is not that easy. Implementing Cognitive Flexibility Theory is not a simple matter of just using the power of the computer to "connect everything with everything else." There are many ways that hypertext systems can be designed, and there is good reason to believe that a large number of those do not produce successful learning outcomes (e.g., because they lead the learner to become lost in a confusing labyrinth of incidental or ad hoc connectionists.) What is needed is the discipline of grounding hypertext design in a suitable theory of learning and instruction. That is what we have done in several prototype hypertext systems derived from Cognitive Flexibility Theory and tailored to the known obstacles to advanced learning in difficult and ill-structured domains (Spiro et al 1988; Spiro and Jehng, 1990). To provide some idea of how theory informs design, consider just one very simple example of a hypertext design decision that responds to the aspect of Cognitive Flexibility Theory-based logic discussed in the last section: rearrangement of the presentation sequence of content that has been investigated previously, In order to produce different understandings when that content is re-read.

**Illustrating the Theory- and Context-Based Logic of Hypertext Design**

Because of the feature of conceptual instability in ill-structured domains (i.e., the same conceptual structure takes on many more meanings across instances of its use than in well-structured domains), Cognitive Flexibility Theory dictates as discussed in the last section, that one kind of instructional revisiting should produce an appreciation in the learner of the varieties of meaning "shades" associated with the diversity of uses. As Wittgenstein argued (1953), the meaning of ill-structured concepts is in their range of uses, rather than in generally applicable definitions - there is no simple "core meaning." We extend Wittgenstein's claim to larger units than the individual concept (e.g., complex conceptual structures such as a theme of a literary work). So, a feature built into our hypertexts is conceptual structure search: content is automatically re-edited to produce a particular kind of "criss-crossing" of the conceptual landscape that visits a large set of case examples of a given conceptual structure in use. The learner then has the option of viewing different example cases of the application of a concept he or she chooses to explore. That is, the instructional content is re-edited upon demand to present just those cases and parts of cases that illustrate a focal conceptual structure (or set of conceptual structures). Rather than having to rely on sporadic encounters with real cases that instantiate different uses of the concept, the learner sees a range of conceptual applications close together, so conceptual variability can easily be examined. Learning a complex concept from erratic exposures to complex Instances with long periods of time separating each encounter, as in natural learning from experience, is not very efficient. When ill-structuredness prevents telling in the abstract how a concept should be used in general, it becomes much more important to show
together the many concrete examples of uses. In sum, a hypertext design feature is incorporated as a response to a learning difficulty caused by a characteristic of ill-structured knowledge domains. (Of course, the issue of example selection and sequencing in a concept instruction has been dealt with before, e.g., Tennyson and Park. 1980. What is novel about the present approach is the particular way that this issue is addressed and the kinds of higher-order conceptual structures that are studied. Even more important is the fact that that single issue is addressed within a larger, integrative framework. (That is, the treatment of conceptual variability is just one aspect of a complete approach in which the diverse aspects are theoretically united.)

Following this same kind of logic, we will sketch briefly some of the other ways that hypertext design features can be made to match the goals of advanced learning—under the constraints of domain ill-structuredness and according to the tenets of Cognitive Flexibility Theory. For this purpose we will use one of our Cognitive Flexibility Hypertext prototypes. Exploring Thematic Structure in Citizen Kane ("KANE," for short - Knowledge Acquisition In Nonlinear Environments; see Spiro and Jehng, 1990, for details), which teaches processes of literary interpretation in a post-structurallst mode (e.g., Barthes, 1967). KANE is a learning environment that goes beyond typical instructional approaches to literary interpretation that too often settle on a single, integrative understanding ("The theme of Citizen Kane is X "). Instead, students are shown that literary texts (in this case a videodisc of a literary film) support multiple interpretations, the interpretations combine and interact, they take on varying senses in different contexts, and so on. For example, the issue of conceptual variability that was discussed above is addressed by providing an option that causes the film to be re-edited to show just those scenes that illustrate any selected conceptual theme of the film (e.g., "Wealth Corrupts," "Hollow, Soulless Man," etc.). Using this option, the learner could, for example, see five scenes in a row, taken from various places in the film, that illustrate different varieties or "flavors" of the "Wealth Corrupts" theme. Each scene essentially forms a miniature case of the Kane character's behavior that illustrates the targeted theme. (Although the student is assumed to have already seen the film one or more times—this is advanced knowledge acquisition for Citizen Kane—the nonlinear presentation may still occasionally confuse; therefore, to deal with this and other kinds of out-of-sequence criss-crossings, a design feature of Cognitive Flexibility Hypertexts is the provision of optional background information on the contexts immediately preceding the one being explored.) Because of the inability of abstract definitions (as might be construed for a theme such as "Soulless Man") to cover conceptual meanings-in-use in ill-structured domains, supplementary guidance about the way meaning is used in a particular situation (Brown, Collins, and Duguid, 1989) is required. This is provided for in KANE by giving the learner the option of reading an expert commentary on the special shade of meaning associated with the conceptual theme as applied to a scene, immediately after the scene is viewed. These functional and context-sensitive (particularized' definitionsexplain why the scene is considered to be a case of a them such as "Wealth Corrupts.") Note that a particularized representation of meaning is not the same as a dictionary sense of a word: the latter refers to different sub-types of a word's meaning, but with an implied similarity or overlap across instances of the same type—so there is less need to tailor to the individual case, in Contrast, particularizing, as we mean it, implies a representation of a concept that is necessarily expressed in terms of an instance of usage (case, example, scene, occasion of use), as required in an ill-structured domain. Commentaries also include information about knowledge access- what cues in the case context should provide a "tip-off" that a particular ccnccept might be relevant for analyzing a case--if one can not access relevant conceptual information in memory, this knowledge will not be useful on subsequent occasions.
The commentaries also provide cross-references to other instantiations of the conceptual structure that constitute an instructionally efficacious set of comparisons (e.g., other cases/scenes in which either a roughly similar or saliently different particularized sense of that conceptual theme occurs). The guiding commentaries also include another important kind of cross-reference, namely to other conceptual themes that have interpretive relevance in accounting for the same case of Kane's behavior, concepts that interact with and influence the meaning of each other in that scene. (Note that these different kinds of cross-references counter the reductive tendencies toward compartmentalization of concepts and their cases of application that we have found to be harmful in advanced learning.) Thus there is a double particularization in Cognitive Flexibility Hypertexts: the generic conceptual structure is particularized not only to the context of a specific case, but also to the other concepts simultaneously applicable for analyzing that case. That is, each case or example is shown to be a complex entity requiring for its understanding multiple conceptual representations, with the role of non-additive conceptual interdependencies highlighted.

Each of the conceptual themes used in KANE is itself a wide-scope interpretive schema that has been argued for in the secondary literature on the film as being the most important theme for understanding the character of Kane. In reality, however, an ill-structured domain has no single schema that is likely to cover everything of interest for an individual case, nor is any schema/theme/concept likely to dominate across a wide range of cases. Therefore the greater the number of such broad-gauge schemata that are available (and KANE provides ten), the greater the utility for understanding in two senses. First, there will be adequate coverage of the complexity of an individual case by an appropriately diverse set of schemata (something which is also modeled in KANE by the simultaneous display of all the relevant conceptual themes in each scene). Second, the likelihood is increased that the most apt set of conceptual schemata will be cognitively available for understanding any one of the highly diverse new cases that will be encountered in an ill-structured domain - the more conceptual structures there are to choose from, each a powerful schema itself and each taught in its complex diversity of patterns of use, the greater the chance that you will find a good fit to a given case. A related virtue is that configurations or combinations of conceptual structures are thereby demonstrated; since multiple conceptual representations will be required for each instance of knowledge application, the ability to combine conceptual entities and to recognize common patterns of their combination is crucial.

The process of situation-specific knowledge construction, so important for transfer in ill-structured domains, is thus supported in at least two important ways: the processes of adaptive knowledge assembly are demonstrated, and the flexible knowledge structures required for this assembly are acquired. Furthermore, as users of the program shift over time into more of a "free exploration" mode, where they independently traverse the themes of the film in trying to answer questions of interpretation (posed by teachers or themselves), their active participation in learning the processes of knowledge assembly increases.

Flexible tools for covering content diversity and for teaching knowledge assembly combine to increase the resources available for future transfer application of knowledge (e.g., interpreting a scene that has not yet been viewed or assembling prior knowledge to facilitate comprehension of a critique written about the film). By making many potential combinations of knowledge cognitively available--either by retrieval from memory or by context-sensitive generation--the learner develops a rich palette to paint a knowledge structure well fit to helping understand and act upon a particular case at hand. This is especially important in an ill-structured domain.
because there will be great variety in the demands on background knowledge from case to case (and with each case individually rich in the knowledge blend required). This discussion could continue for many other features of Cognitive Flexibility Hypertexts that are specifically derived from Cognitive Flexibility Theory. What would be in common across any such discussion is that each feature could be shown to have the following purpose: to counter an advanced learning difficulty endemic to ill-structured domains.

**Concluding Remarks**

We have just discussed a few of the many kinds of revisitings of instructional content in rearranged contexts that are implied by Cognitive Flexibility Theory and embodied in our hypertext systems. However our goals in this paper were necessarily limited. Our purpose was merely to begin to illustrate the way design features of a particular kind of computer learning environment are related to cognitive and instructional theories that are themselves based on the problems posed by the interaction of learning objectives and characteristics of ill-structured knowledge domains. That is our intention was to illustrate a way of thinking about the design of hypertext learning environments that is sensitive to and dependent upon the cognitive characteristics necessary for advanced knowledge acquisition in ill-structured domains. In particular these are the characteristics of the new constructivism that we discussed earlier and that are properties of Cognitive Flexibility Theory. The realm of constructive processes must be taken beyond the retrieval of knowledge structures from memory (for the purpose of going beyond the information given in some learning situation) to also! include the independent, flexible, situation-specific assembly of the background knowledge structures themselves.

In sum, we consider our work to be moving towards a systematic theory of hypertext design to provide flexible instruction appropriate for developing cognitive flexibility. We have called the instructional theory that is derived from Cognitive Flexibility Theory and applied in flexible computer learning environments Random Access Instruction. It and the developing hypertext theory is laid out in considerable detail in Spiro and Jehng (1990). We are encouraged so far about the robustness, systematicity, and generality of our hypertext design principles in that they have been applied in very similar ways to develop hypertext prototypes in domains as diverse as cardiovascular medicine literary interpretation and military strategy. Preliminary data on the effectiveness of these Cognitive Flexibility Hypertexts- is also encouraging. For example, Jacobson and Spiro (1991a) investigated two different design approaches for structuring a hypertext learning environment to provide instruction in a complex and ill-structured domain (the social impact of technology). The results of this experiment revealed that while the design which emphasized the mastery of declarative knowledge tied to higher performance on measures of memory for presented facts the design based on Cognitive Flexibility Theory (which highlighted different facets of the material by explicitly demonstrating critical interrelationships between abstract and case-centered knowledge components in multiple contexts on different passes through the same content) promoted superior transfer to a new problem-solving situation. More empirical testing is clearly required and numerous other issues of hypertext design remain to be discussed. However, those are stories for another time.

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